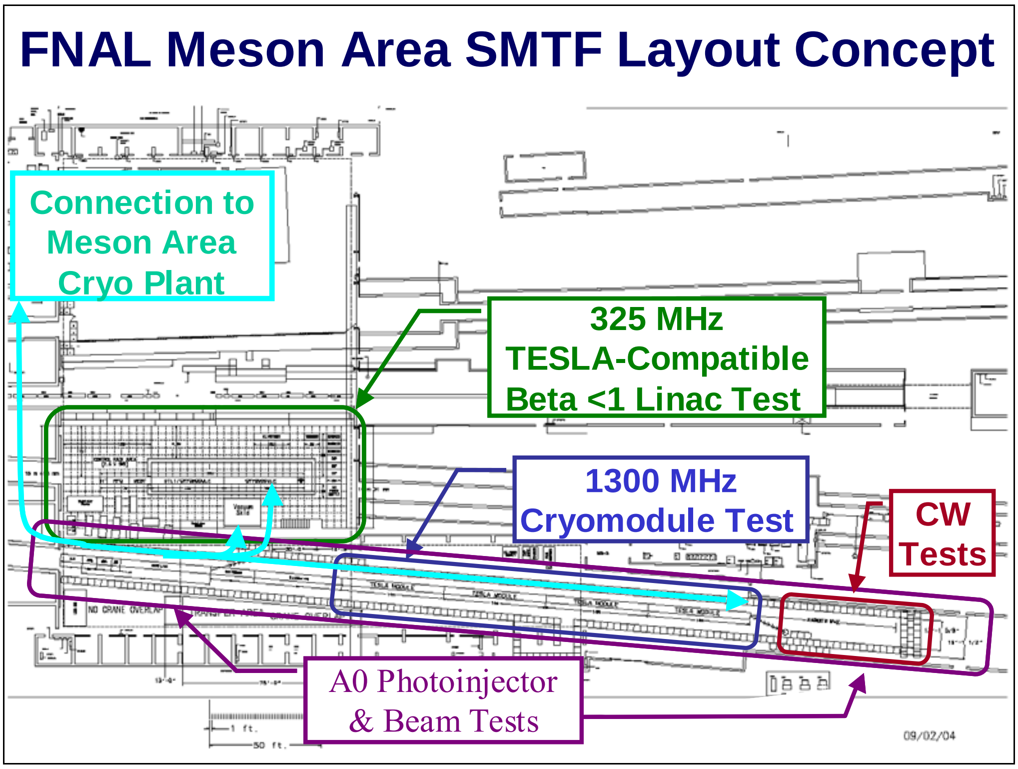
Expression of Interest for the Superconducting Module Test Facility (SMTF)



Participating Institutions

Argonne Laboratory (ANL), Brookhaven (BNL), Cornell University, Fermilab, Jefferson Laboratory (JLAB), Lawrence Berkeley National Laboratory (LBNL), Los Alamos National Laboratory (LANL), MIT-Bates Laboratory, Michigan State University National Superconducting Cyclotron Laboratory (MSU-NSCF), Northern Illinois University (NIU), Spallation Neutron Source (SNS) at Oak Ridge, University of Pennsylvania, and Stanford Linear Accelerator Center (SLAC).

Contact: Helen Edwards hedwards@fnal.gov, Nigel Lockyer lockyer@fnal.gov, or Shehkar Mishra mishra@fnal.gov

Executive Summary

This Expression of Interest (EOI) describes a new US initiative in Superconducting RF (SCRF) research and development. The goal is to develop capabilities in high gradient and high-Q SCRF superconducting accelerating structures and related subsystems in support of the International Linear Collider (ILC) and other accelerator projects of interest to US laboratories. It is envisioned that a central facility, designated the Superconducting RF Module Test Facility (SMTF), will be constructed in the "Meson Area" at Fermilab by a consortium of US laboratories and universities led by Fermilab. The SMTF will seek to complement existing SCRF infrastructure present at other U.S. laboratories. This effort should also facilitate the formation of a U.S. SCRF accelerator collaboration that will eventually develop, along with our international partners, a design for the ILC main linac The facility will be constructed in phases, roughly over the period 2005-2008.

The centerpiece of SMTF will be the ILC electron beam test facility, with shared infrastructure supporting an additional two test areas for β<1 and CW accelerating structures in support of other programs of interest within the U.S. (such as RIA, Proton Driver, and 4th generation light sources). Possible collaboration with the international HEP laboratories DESY and KEK is being discussed as part of the global R&D program for the ILC.

There are three main areas of emphasis:

1) The ILC work falls into two categories:
    a. Fabrication in the US of three 1.3 GHz high gradient cryomodules.
    b. Establish a high gradient 1.3 GHz cryomodule test area at Fermilab with a high quality pulsed electron beam using an upgraded A0 injector.
2) Establish a CW test area that will extend the reach of present US program in CW capabilities (4th generation light sources and other related community activities). Includes RF, cryogenics, controls, and safety infrastructure to support high power RF testing of β=1 accelerating structures in CW (100% duty factor) mode. The possibility of pulsed beam is being discussed.
3) Establish a β < 1 test area for the Proton Driver and RIA cavities. Includes RF, cryogenics, controls, and safety infrastructure to support high power RF testing of β<1 accelerating structures in pulsed mode (~1% duty factor).

The specific goals include:

- Demonstration of superconducting structures with 35 MV/m accelerating gradients operating at 1.3 GHz, in pulsed operation with a 1% duty factor and with high beam loading, for ILC applications.

- Development of the capability to fabricate high gradient SCRF structures in the US using a combination of industry and laboratories for the ILC.
- Development and demonstration of high gradient, pulsed mode, $\beta<1$ cavities at 325 MHz for RIA and Proton Driver applications.
- Demonstration of 20 MV/m CW operations for light source applications.

We imagine the SMTF being constructed in the Meson experimental area at Fermilab, in a series of phases, over the next several years.

- Phase 1: Installation of infrastructure culminating in the RF power tests of a single ILC cryomodule within the high gradient pulsed test area. This cryomodule is anticipated to be provided by DESY. Relocation and commissioning of the Fermilab NICADD photo injector in the SMTF.
- Phase 2a: Initiate beam tests of a single ILC cryomodule utilizing the photo injector. Commission the $\beta < 1$ and CW test areas.
- Phase 2b: Install, and operate with beam, a complete ILC RF unit consisting of four high gradient cryomodules, fabricated by the SMTF collaboration with industrial partners.

Phase 3: At the end of Phase II a significant, and flexible, facility will exist with opportunities for evolution in a variety of directions. We anticipate that future development of the facility beyond Phase 2b will be determined in consultation with the ILC Global Design Initiative, and in consideration of the status of the Proton Driver or other projects of interest to U.S. laboratories and funding agencies.

The $\beta<1$ test area is expected to evolve in a similar manner. The initial scope will include a 325 MHz pulsed RF system tests and a test cryostat for pulsed-mode operation of RIA-type SCRF spoke resonators. In later phases of operation, members of the SMTF collaboration would add an H- source, and Radio Frequency Quad (RFQ), and medium-energy beam transport (MEBT) powered by the same pulsed Klystron that operates the SCRF cryomodules. This would provide a beam-based test bed for LLRF and resonance control when driving low-beta ion beams with multiple cavities driven from a single Klystron.

This Expression of Interest outlines the rough goals and scope of the SMTF project. We expect that a dialog with Fermilab, the participating laboratories, and funding agencies will commence after this report is reviewed. In response to this EOI the collaboration hopes to receive guidance on how to proceed with the next steps toward a full proposal.

Introduction and Motivation

A variety of projects are being planned in particle physics, nuclear physics, and fields of basic energy sciences such as condensed matter physics and biological physics that propose to use superconducting RF (SCRF) linac technology. These projects are distributed across many of the major US laboratories funded by DOE and NSF. This expression of interest is to inform Fermilab management that we will propose to construct a superconducting RF module test facility (SMTF) in the meson area at Fermilab. A medium energy electron beam and a low energy H- beam would permit a unique opportunity for characterization of the properties of superconducting RF cavities and for beam-related experiments. The members of the team, led by Fermilab, are a consortium of several US laboratories and universities.

We list several possible future projects that will use RF Superconductivity.

1) International Linear Collider (ILC)
2) The Rare Isotope Accelerator (RIA) (located at Argonne or MSU) would use a SCRF linac. RIA will help drive the development of SCRF in US industry.
3) Proton driver (if cold linac option) at Fermilab and BNL.
4) Upgrades (12 GeV) to JLAB electron linac, the extensions of the FEL and the proposed ELIC (Electron Light Ion Collider)
5) SNS (Spallation Neutron Source) upgrades to achieve higher beam power ~ 4 MW.
6) Fourth generation light sources at ANL, BNL, Cornell, JLAB, LBNL, and MIT using SCRF linac technology for ERLs (energy recovery linac) or FELs (free electron laser).
7) Brookhaven plans to use ERLs for electrons colliding with RHIC heavy ion beams (E-RHIC) and for electron cooling of the RHIC beams.

These projects have common or similar systems and developments that could benefit from coordinated efforts. Several of the laboratories have infrastructure to carry out SCRF development as well as limited fabrication capabilities. These efforts in SCRF are broadly funded by USDOE HEP, Nuclear, Basic Energy Sciences and the NSF. Many of these projects would benefit directly from a common module test facility not available in the US at present. We propose a SCRF Module Test Facility (which we refer to as the SMTF) that would address the gaps in the existing technology R&D. Fermilab would be the lead laboratory.

The common R&D goals across many proposals are:

1) Demonstrate 35 MV/m at 1% duty factor with high beam loading at 1300MHz for ILC applications.
2) Demonstrate 20 MV/m CW operations at Q values > 3E10.
3) Operate at 20 MV/m at a Q_ext > 1E7 for low beam loading applications.

(Necessary in order to keep CW RF power demands within reasonable bounds.)

4) Demonstrate > 15 MV/m high duty factor operation at beta~0.5-0.8 at Q>5E9 for 1.3 GHz elliptical cavities with multiple cavity operation from one klystron (proton driver).
5) Demonstrate high gradient for pulsed mode beta < 1 cavities and cryomodule at 325 MHz, for proton driver and related applications.

These goals encompass research and development topics critical for the continued iteration and evolution of SCRF linac systems, for the development of cost effective low to medium beta linac sections needed for proton/ion linacs, and development of CW operation for the many upcoming light source applications.

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Proposed Plan

We propose to develop the meson east area into a cryomodule test area. The allocated space should be able to accommodate initially three test areas, two of which are along a beam line of length of 100-150 meters, the high gradient pulsed work and the CW activities. A second area should be large enough to accommodate the 325 MHz β<1 cryomodule activities. We anticipate three different communities using the facility. One community will concentrate on 1.3 GHz pulsed high gradient tests, such as needed for the ILC, another community will focus on cryomodule operation needed for the fourth generation light source and FEL accelerators that use high Q, CW operation, and one community will emphasize 325 MHz β<1 activities. We envision that the regions will initially operate in two different modes. In one region, physicists would perform high power cryomodule tests as well as beam tests with a medium energy electron beam (100-300 MeV). In the parallel region tests (initially without beam) could be ongoing low beta demonstration cryomodules. Shielding between the two regions will be necessary for flexible operation. The details of the layout are still being worked out.

The electron beam test area in SMTF would consist of an electron beam injector, a beam analysis region after the injector and before the cryomodules in order to measure incoming beam properties, a section of up to four cryomodules, which constitutes one RF unit, and space afterwards to evaluate the outgoing beam properties. The CW activities are located downstream of the ILC cryomodules. The existing Fermilab FNPL (A0 injector) would be an appropriate initial source. This consists of a gun and accelerating section, and is about 15 m (upgraded eventually to 25 m) in length. We estimate that 20 m of beam analysis space is needed to measure beam properties, followed by space for four 12-17 m cryomodules, and an additional 20 m of analysis space for the outgoing beam and a beam dump, for a total of 100-150 m.

The cryogenics plant in the meson area needs to be upgraded. We propose a two step approach. For the first step we make minimal modifications to the existing infrastructure and utilize what we can to supply the area quickly with about 60 watts of refrigeration at 2K. Each TESLA cryomodule consumes about 6-10 Watts of refrigeration at 2K. The second step requires a refrigeration plant that can handle >300 watts. Medium energy electron beams will be used for testing the cryomodules in the area and dark current should be expected from the cavity modules, therefore the appropriate radiation shielding will be necessary for each test area. The cryogenics are described in Appendix C.

To get started quickly we will propose to use DESY high gradient cavities and a DESY cryomodule. In parallel, we would aggressively move to construct cavities, auxiliary components (couplers, tuners, helium vessels), and cryomodules in the US. We note that US industry considerably lags European industry in SCRF technology and our plans would help correct this situation. This is especially desirable given the large number of SCRF projects in the US. We plan to incorporate existing infrastructure and expertise at US labs as well as US industry to build cavities, carry out bare cavity tests in vertical Dewars, and assemble cavity strings and cryomodules. In addition we would build couplers and tuners and other cryomodule components to extend the full range of expertise and technology required for the major projects envisioned. As the lead laboratory, Fermilab would coordinate many of these activities with the participating laboratories and industry. Significant infrastructure already exists at the participating labs to carry out these activities. See appendix two for more details cavity and cryomodule fabrication.

We plan to expand the infrastructure at Fermilab to have the ability to make measurements on “bare” 3.9 GHz cavities in collaboration with Argonne. A test system will require space for a vertical Dewar and possibly a horizontal single cavity test cryostat. These will be needed to accomplish measurements on both bare and dressed cavities. We plan to adopt the DESY Dewar and cryostat designs[1].

The document is organized around the three main SCRF areas: ILC, CW, and the □< 1 programs. Even though we present the three research concentrations separately for ease of reading, the resources and goals significantly overlap and are intermingled.

ILC Test Facility - A Phased Approach

We plan to proceed with two main phases in the development of an ILC module test bed. (See Figure 1.)This expression of interest addresses the first two phases, and the third is listed to highlight a possible goal.

1) Bring into operation one TESLA like module with RF and cryogenics, with the goal of demonstrating 35 MV/m. (This may take more that one iteration.)

2a) Install the A0 injector with the one TESLA like module (step 1) in order to perform beam measurements, which are discussed below.

[1] The vertical Dewar is actually a Fermilab design (Fermilab’s contribution to TESLA).

2b) Bring into operation one "RF unit" of 3 or 4 modules (32-36 cavities) and an injector[2] so that beam measurements can be carried out.
2c) Upgrade the injector to use an 8 cavity TESLA module instead of 2 TESLA cavities as presently planned. This development could be used as an electron injector to the ~1% ILC demonstration machine (or as an eventual unpolarized injector for ILC).

3) Possible 1% demonstration machine if requested by Global Design Initiative (GDI).

Steps 1) and 2) will provide a vehicle for iteration of component and systems designs as they evolve toward final industrial prototypes. They also provide for further investigation and iteration of beam and accelerator measurements. Though these steps are closely aligned with similar activities at TTF, we believe it is imperative for a project the size of ILC that each region carries out fundamental developments of the large systems, such as the linac[3]. The SMTF-ILC Test Bed would allow for testing with different klystrons, couplers, Low Level RF (LLRF) systems, and performance under beam loading conditions as well as measurements of beam properties. The SMTF might also act as the main database for these test results.

The ~1% ILC demonstration is an important vehicle for development of "low rate" industrial production and a firm understanding of costs for the ILC production. The preliminary outline of time scale for the three steps called for 1) 2005-2006, 2) 2006-2008, 3) 2008, and beyond.

[2] Transplant the A0 photo injector (A0PI)
[3] We expect availability of TTF will be very limited due to its transformation into a FEL user facility

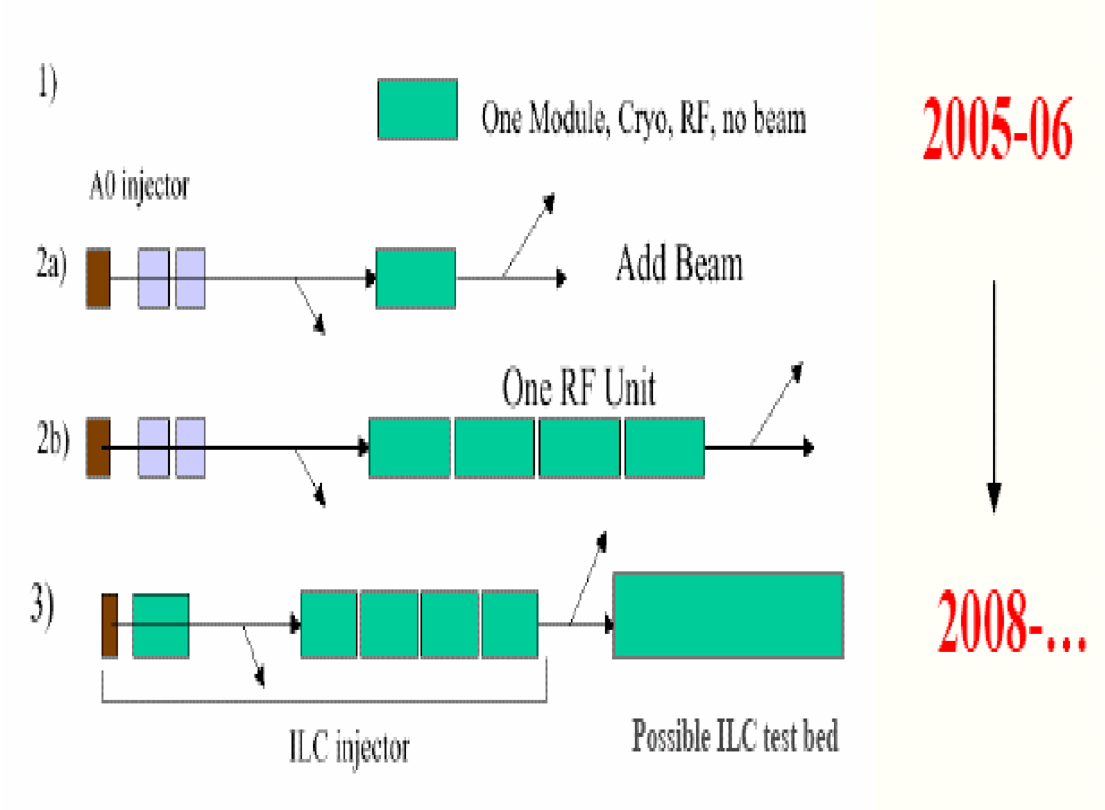

Figure 1 Phased commissioning of the 1.3 GHz cryomodule and beam test facility

We plan to begin with the DESY high gradient cavities and a DESY cryomodule to get started quickly and in parallel we would aggressively move to construct cavities, auxiliary components (couplers, tuners, helium vessels), and cryomodules in the US. We note that US industry considerably lags European industry in SCRF technology and our plans would help correct this situation. This is especially desirable given the large number of SCRF projects in the US. We would want to first test a high gradient Tesla cavity (35 MV/m) in order to establish a reference performance cavity and cryomodule. A single or perhaps a few cavities, depending on availability, would be installed in a cryomodule supplied by DESY. We would then establish high gradient performance along with Q and dark current measurements without beam. Tuner tests with the cryomodule would be performed to establish the necessary specification. Beam commissioning could proceed after the static tests were complete.

We think it important to follow a parallel path of constructing and processing new cavities and cryomodules in the US. As an example scenario, we would propose to first construct β=1 pure niobium cavities (Cornell and US Industry) using the Tesla design in US industry. We would use the BCP process for the cavities using the facilities at JLAB, Argonne, or Cornell. Cornell would vertically test the cavities in a vertical Dewar. JLAB would then do the electro polishing, and then attach the input couplers, helium vessel, and tuners. The input power couplers would be procured from industry. JLAB would perform the horizontal Dewar test of the individual dressed cavity. LANL would design and co-ordinate building a cryomodule (Tesla design) along with industry. The cryomodule would accommodate 8 cavities (up to 12 cavities might be in a next generation cryomodule design). The end caps will be designed at LANL and procured from industry. The final assembly of the individual dressed cavities into a cryostat will be done at Fermilab. To accomplish this will require expansion of the clean room area and installation of cryomodule assembly fixtures. (Other scenarios are possible with different labs carrying out the proposed activities)

Power for One Complete RF unit (steps 1 and 2)

The RF power system will have to accommodate one complete pulsed RF unit at 1.3 GHZ at the facility. (For 1.3GHz an RF unit is similar to that defined for TESLA, either 3 12 9-cell cavity modules of 17 m each, or 4 8 9-cell cavity modules of 12 m each.) Each RF unit is powered by one 10 MW klystron. The 1.3 GHz klystrons would be purchased from one of three vendors used by DESY: Thales has produced a 10 MW Klystron to the required specifications, CPI has a prototype that has reached 10 MW but has some remaining pulse length issues although they are thought to be understood. Toshiba will produce a first prototype by this summer. Initially power for an RF unit could be provided by a 5 MW klystron that is presently a spare at the A0 injector (See below).

Two modulators for SMTF are currently under construction at Fermilab. These are designed specifically to power any of the following: the 10 MW 1300 MHz multi-beam Klystrons from Thales, CPI, or Toshiba; the 325 MHz JPARC/Toshiba Klystron planned for the beta<1 linac, or the existing spare 5 MW 1.3 GHz klystron. The modulators can be reconfigured to support pulse widths of 1.5 msec, 3 msec, or 4.5 msec used by the ILC and Proton Driver.

The Injector

Three Possible Upgrade Plans

The A0 photo injector will be moved to SMTF and will be upgraded in a phased approach. The present plan at A0 is to reconfigure the injector to include: a normal conducting gun, and two Tesla cavities (one operating at 12 MV/m and one at 25 MV/m). This configuration requires a high power klystron/modulator system (~4-5 MW) for the normal conducting gun, and two low power systems (~300 KW nominal each) for the two Tesla cavities. The high power modulator system is very similar to that discussed above for a 10 MW klystron. The main difference is the multi-beam klystron with its higher efficiency. Both the gun and the modulator would need to be upgraded for 5 Hz long pulse operation.

A further step would incorporate two 3.9 GHz cavities of two different designs, presently under development. One of these cavity types (3rdHar) is operated in deceleration mode and linearizes the beam bunch energy with time. The other operates in a deflecting mode and is used as a diagnostic to measure beam properties within the different time slices of the beam bunch. The cavities require ~4 KW power. To implement these two cavities requires two additional low power modulators; one of which is similar to that needed for the individual TESLA cavities (above), and one that is a gated CW modulator.

Eventually it might be desirable to upgrade the injector to a system similar to that now at TTF. (This is schematically illustrated in step 3 of Fig. 1. The two TESLA cavities would be replaced by an 8 cavity module with some of the cavities operating at ~12MV/m and the rest at~25 MV/m. This module would require a high power (5 MW) klystron/modulator system. The one 3.9 GHz decelerating cavity would be replaced by a module of 4 3rdHar cavities and would require an 80 KW klystron that could actually be the same unit as before, but operated at higher power. See Appendix for a more detailed discussion,

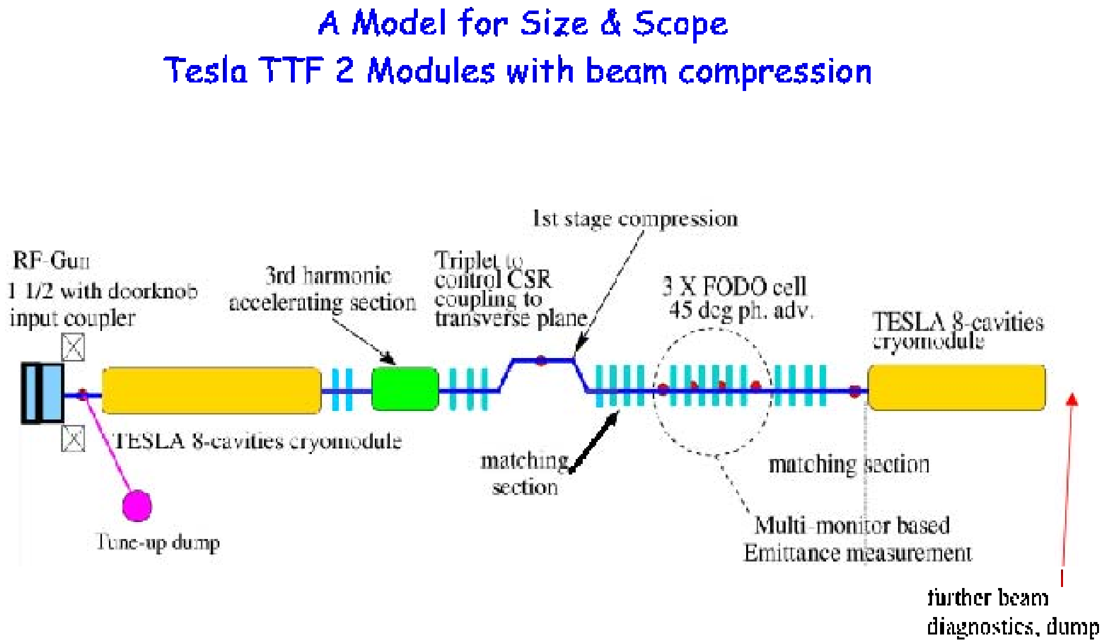

Figure 2 Upgraded Photo injector

Two Possible Power System Configurations

We presently have two 5 MW Klystrons at Fermilab from Thales, one of which is used for the A0 injector gun. We envision two possible power system configurations for the upgraded A0 injector. After the gun, there is a 12 MV/m Tesla cavity followed by a 25 MV/m cavity. Each of these cavities requires 250 KW of klystron power. These cavities are followed by a 3.9 GHz accelerating mode 3^{rd} harmonic structure which requires 4 KW of klystron power[4]. After magnetic bunch compression, an additional 3^{rd} harmonic deflecting mode cavity requires 4 KW of power[5].

[4] This would correspond to a beam current of about 3 mA, to reach 8 mA one would need at least 10 kW, better 12 kW to have some margin. That's a pulsed klystron with modulator and all, the other might have been a small cw amplifier. At A0 we plan to limit the current during 3^{rd} harmonic operation.
[5] Here 2.5 kW are sufficient for diagnostic purposes (and all the parts are available already)

Alternatively[6], a full 8-cavity Tesla cryomodule could replace the first two cavities after the gun[7]. The cryomodule would require a 5 MW klystron (second available 5 MW klystron). The accelerating mode 3rd harmonic cavity would be upgraded to have four such cavities which require 80 kW of power, before the bunch compression. One 10 MW multi-beam klystron is needed for the downstream complete RF unit of 4 Tesla cryomodules.

Klystron Summary

In summary there are five klystron types proposed in this layout. The four pulsed units are: 5 MW Thales, 10 MW MBK, 300 KW Phillips (all at 1.3 GHz), 80 KW 3.9 GHz CPI. The 3.9 GHz 4 KW CW klystron is CPI.

There are three modulator types: Hi Power (5-10 MW), Low Power (300-80 KW) and gated CW (4 KW).

Modulator Summary

The Fermilab designed modulator will be adequate for the test facility. If we employ the full 8-cavity cryomodule, then 3 large modulators and 2 small 3.9 GHz modulators are needed or 5 total are required[8]. One modulator handles 4 8-cavity cryomodules. The gun requires a high power modulator and the first cryomodule of the injector also requires a modulator as does the downstream RF unit. The 325 MHz klystrons have considerable overlap with those at JHF. The Fermilab modulator should be able to accommodate 325 MHz.

Cryogenics Needs

The cryogenic need for phase 1) and through phase 2b) is 60 watts at 2 degrees K. There are thermal three shields, operated at 2.0K, 4.5K, and 80K. The 80Kshield will be liquid nitrogen, the 4.5K shield is gaseous helium, and the 2.0K shield is super fluid helium.

Other items that will be needed are the phase separators, control systems, vacuum pump (sub-atmospheric to lower temperature to 2 K.), transfer lines, and feedbox. The feedbox contains low pressure heat exchanger, numerous control valves and instrumentation. It must connect to cryomodules via an input cryogenic feed cap and

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6 in the last phase of the project

7 The injector would have to be arranged such that there is space enough to insert this at a later time

8 In the first phase two small (300 kW) modulators for the two 9-cell cavities would be required. These are two of the three we plan to build for A0, the third one is for the 80 kW for the 3rd harmonic.

output cryogenic end cap.

Care in avoiding contamination of the helium is necessary because the system is running sub-atmospheric. This implies that regular maintenance for decontamination will be necessary. This is not a problem but will
reduce the availability.

One additional complication at phase 2a) is the requirement that the cryogenic distribution must feed the cryomodule and the three connections to the A0 photo injector. Three additional smaller feedboxes will be have to be constructed.

The schedule length needed to install the cryogenic distribution system is about 6 months. The feedbox will require about 9-12 to complete.
A large lead item for phase three is a 300 Watt 2 K refrigerator. It is estimated that this is a two year lead. There are at least two companies that can build this and possibly others.

See the appendix for a more detailed discussion of the cryogenic system.

Electron Beam Tests

We outline below possible studies with a 100-300 MeV electron beam for the SMTF. First, the RF performance of the cavities can be measured directly with beam and secondly, the impact of the cavity on the beam can be assessed. An initial set of measurements would include:

- Beam energy: a spectrometer would provide an independent and accurate measurement of the accelerating gradient. RF techniques are not as accurate.
- Long Range wake-field characterization: HOM impact on multi-bunch dynamics (emittance and energy spread). Especially important for high repetition linacs such as high power free electron lasers and electron cooling at RHIC. High beam currents may allow the observation of the beam break-up instability.
- Tests of low-level RF: compensating beam loading effects on the beam energy spread
- Impact of the SCRF cavity on transverse beam dynamics: measure the cavity transfer matrix and impact of field asymmetries near the input power and HOM couplers on beam dynamics.

This broad range of measurements will present several technical challenges, the details of which have to be worked out. Shown in the figure is a possible layout for the electron beam source.

CW Test Area and Program

Superconducting Linac-based Free Electron Lasers (FELs) and Energy Recovery Linacs (ERLs) are accelerator advances that allow high peak brilliance, high coherence and ultra short light pulses covering wavelengths from infra-red to X-rays, depending on the beam energy. ERLs allow high average photon flux by using very high beam power but recovering the beam energy upon recirculation through the linac. Recently JLAB recovered 800 kW beam power by recirculating 6 mA of beam current. LBNL and MIT are developing CW FELs based on TESLA technology. Cornell and JLAB are developing ERLs based light sources. Cornell for example is conducting a study towards 100 ma, 5GeV beam with the equivalent of 500 MW of power with energy recovery. A high-current ERL is under construction at BNL. The objective is to demonstrate 0.5 ampere CW current at about 20 MeV. The ERL will use a ½ cell SRF photo injector and a 5-cell linac cavity at 703.75 MHz. BNL expects to demonstrate 20 MV/m CW operations at Q values > 3E10 and Q_ext > 1E7 for low-beam-loading applications. The facility will be operational by the end of 2006 as R&D towards electron cooling of RHIC."
As a result of recovery, an ERL has low beam loading, since the "return beam" trails the lead beam (out of phase) and re-charges the cavity. Since an ERL operates with low beam loading, a test beam is not crucial for qualifying these cryomodules
It is essential that the CW machine achieve high Q values> 3E10. Even at TESLA Q values of 1E10 (2 K operating temperature), the power loss at 20 MV/m is 40 Watts/m, as compared to the Tesla pulsed operation of 1-2 Watts/m. Lowering the temperature to 1.8 K increases the theoretical Q reachable to more than 6 E10. Allowing for a factor of two Q reduction due to residual losses, a target Q of 3E10 would reduce the dynamic heat load to 13.3 watts/m. But excellent magnetic shielding will be necessary to screen the earth's field down to about one milliGauss. (The earth's field flux quanta get trapped in the niobium walls, due to the presence of imperfections, impurities and oxides, thereby limiting the Q-value). Running at 1.8 K to reduce the BCS resistance and increase the theoretical maximum Q-value will demand larger pumps to reach the lower helium vapor pressure corresponding to 1.8 K. Although the cold gas return (output) lines can be kept the same as the Tesla module the liquid helium supply line would have to be increased to deal with the larger dynamic heat load. There will be additional static heat loads of about 1 watt per meter at 1.8 K and 3 watt/m at 4.5 K. Allowing for a safety factor of 1.5, the CW cryomodule refrigerator would be sized for about 22 watt/m at 1.8 K and about 5 watt/m at 4.5 K.

The CW tests will require a klystron (or IOT) with about 15 KW/meter of power to establish 20 MV/m operating field with control margin for dealing with micro phonics at the optimum external Q value, estimated to be about 2E7. A high voltage power supply and a small amplifier are needed to supply the klystron. CPI, Thales, or E2V are possible suppliers. The cryomodule and cavities can be constructed in US industry using existing infrastructure at US labs. For example, cavities could be fabricated by AES, processed at JLAB, and vertical tested at Cornell. The cryomodule components could be constructed at Meyer Tool and assembled at LANL or JLAB. The string assembly can be at JLAB or LANL.

Beta < 1 Test Area

There is a desire at Fermilab to participate in a world class program in neutrino physics, building on the lab's rich neutrino history, and the exciting (non-accelerator) results from SuperK (Japan) and SNO (Canada). This neutrino program, presently being discussed, consists of a major new accelerator, referred to as the proton driver, and a new ``off-axis" experiment. The cold linac option for the proton driver is the preferred technical solution by the lab for upgrading the neutrino flux by a factor of about five. The possibility of observing CP violation on the lepton sector may be important physics to our understanding of the matter antimatter asymmetry in the universe, and deserves a significant investment. The proton driver will need 288 TESLA cavities in 36 cryomodules, as well as 96 low beta elliptical cavities in 12 cryomodules, all at 1.3 GHz.

The Proton Driver is an 8 GeV proton linac. The last 85% of the linac (1 GeV to 8 GeV) is comprised of beta=1 TESLA modules and will benefit from the ILC program. The synergy between ILC R&D and Proton Driver is further reinforced by the almost complete overlap of an ILC module test bed (Steps 1&2) and what will be needed for many aspects of Proton Driver R&D.

Two main uses are foreseen for the $\beta < 1$ test area: pulsed-mode front end linac for the Proton Driver, and a possible production test facility for RIA cavities and cryomodules.

The initial RF systems will support pulsed mode operation at 325 MHz (one quarter of the ILC's 1300 MHz) and extend the TESLA-style RF fan out from one large Klystron to a large number of cavities. This will support development of a family of "ILC-compatible" beta<1 superconducting cavities to be developed by members of the SMTF collaboration. These include single, double, and potentially triple spoke SCRF cavity resonators. [At higher beta, the Proton Driver will also use cryomodules with 1300 MHz elliptical cavities that will be tested in the 1300 MHz test area].

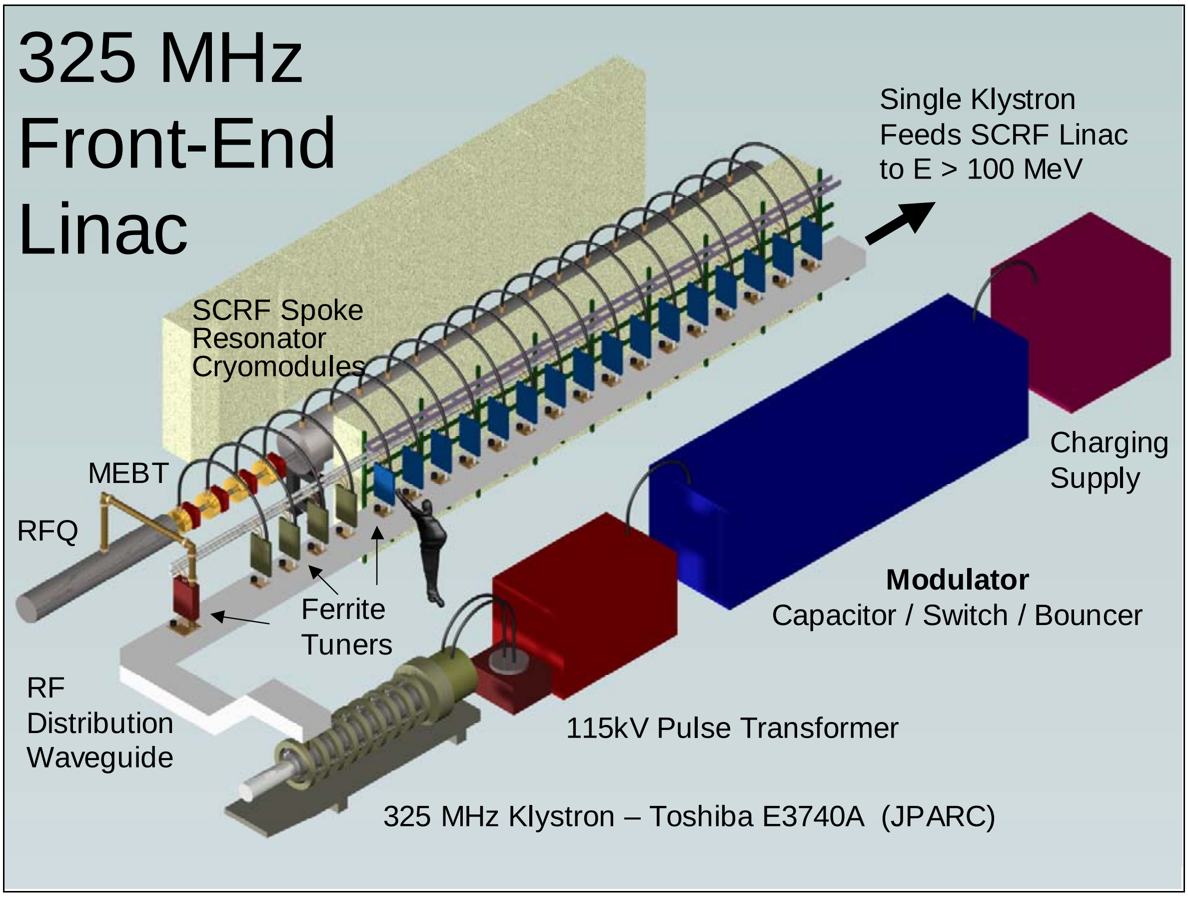

Fig. 3 - Beta <1 test area. The entire front-end linac is driven by a single 325 MHz klystron. Although the single klystron should be capable of driving the entire front end linac up to an energy of ~100 MeV, the beam energy will be limited to ~30 MeV by the length of beam line enclosure available.

Beam Tests. A second phase of operation would add an H- source, and RFQ, and Medium Energy Beam Transport (MEBT) operating from the same pulsed Klystron that operates the SCRF cryomodules. This would provide a beam-based test bed for LLRF and resonance control when driving low-beta ion beams with multiple cavities driven from a single Klystron. Emittance measurements, chopping, and laser stripping experiments will be possible.

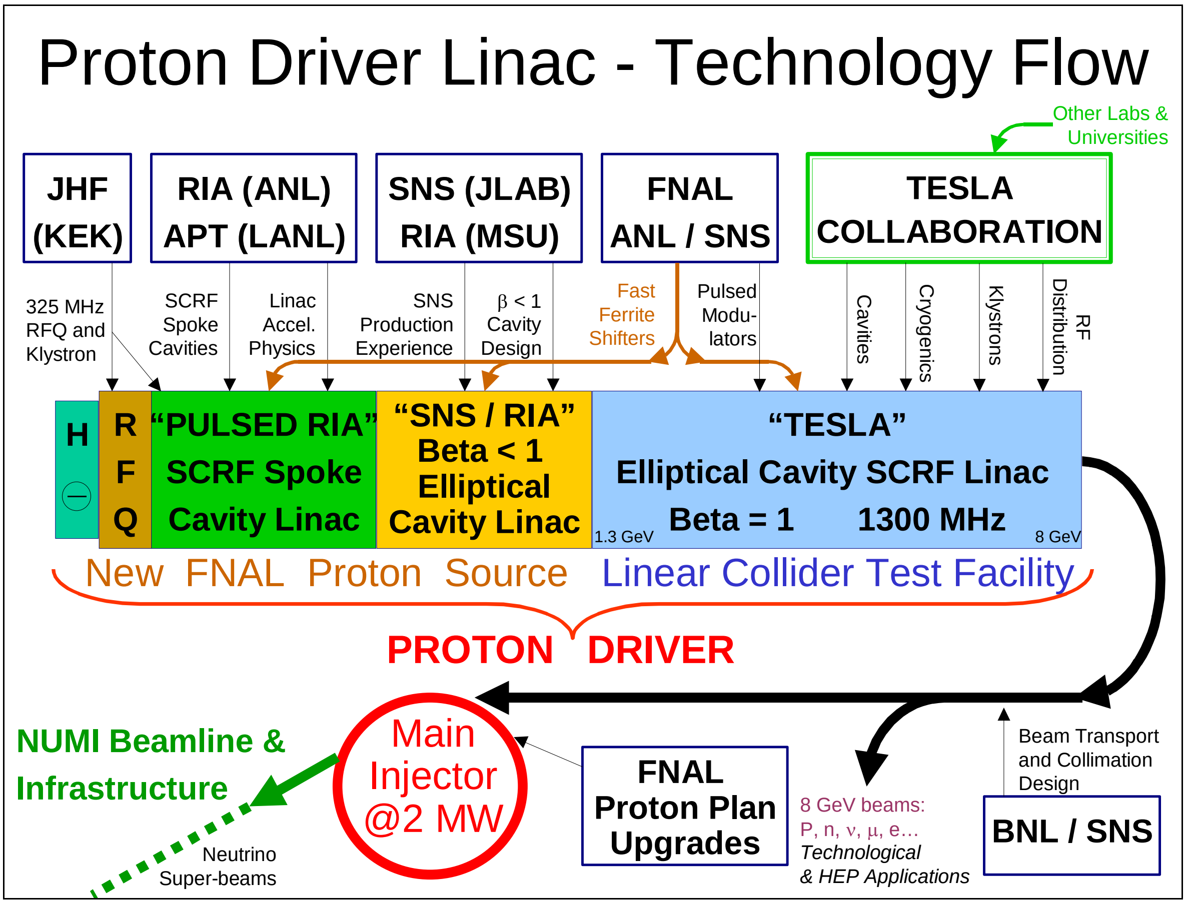

Fig. 4 – Evolution of technology to be tested in SMTF beta< 1 linac. The beta<1 test area would support a 325 MHz front end linac pattered on the JHF/JPARC front end, then use SCRF spoke resonators patterned on the RIA cavities. The 1300 MHz test area would support beta<1 elliptical cavities and cryomodules, as well as beta=1 section patterned on the ILC main linac.

325 MHz Pulsed RF Systems for Beta<1 Test Area

A single 3MW Klystron (the Toshiba E740A currently in production for JPARC) will provide pulsed RF power for the 325 MHz beta<1 linac. See fig.5.

The RF systems would be designed to support both the initial and upgrade beam pulse parameters for the Proton Driver. Initial operation would support beam pulses of (8.3 mA x 3 msec x 2.5 Hz), with an upgrade scenario requiring (25 mA x 1 msec x 10 msec). Two modulators are currently under construction which can be reconfigured to support either of these pulse parameters.

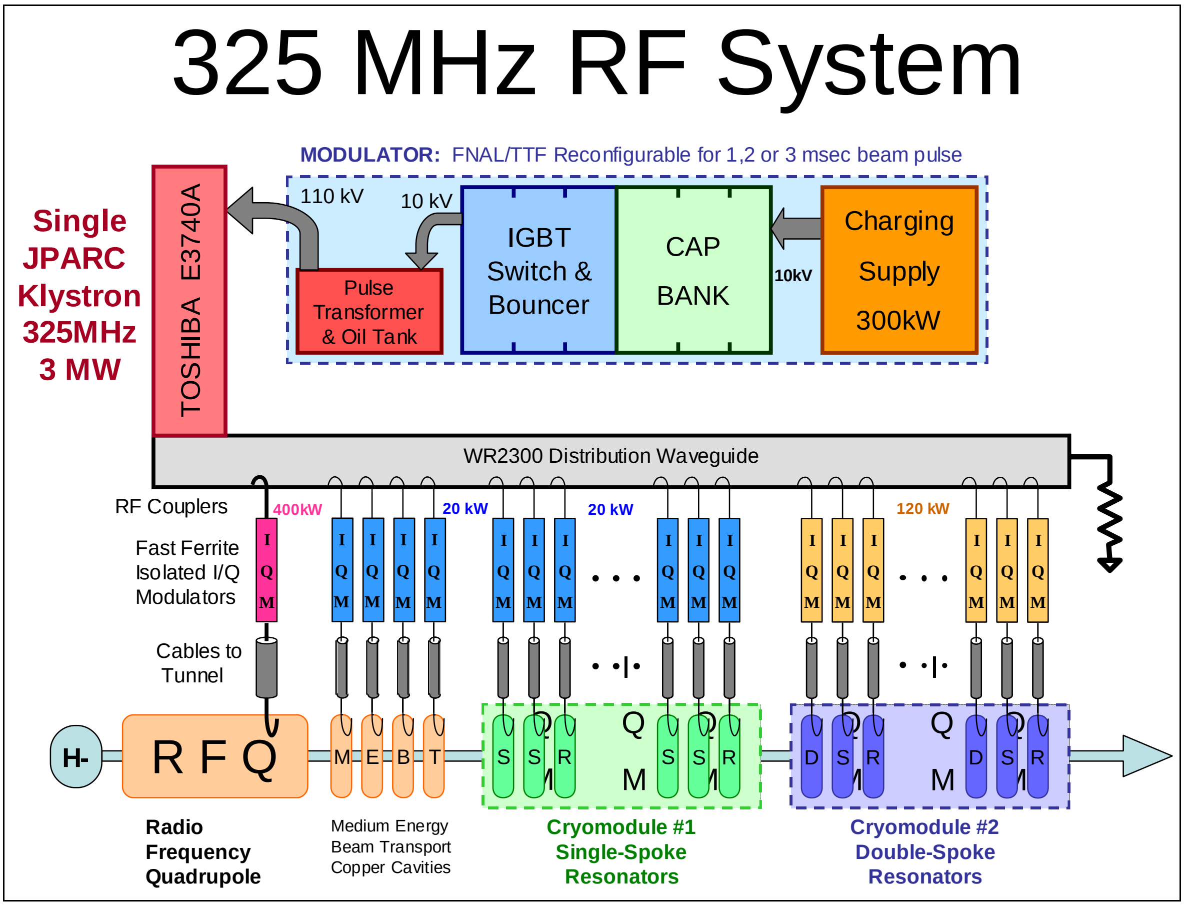

Fig. 5 - The RF distribution system for the 325 MHz beta<1 pulsed SCRF linac. In a TESLA-like scheme, directional couplers are used to split off power for each cavity from a long waveguide running parallel to the linac. Individual resonance control for each cavity iis provided by fast tuners using magnetically biased YIG ferrite to provide individual phase and amplitude control for each cavity.

Program sequence for the 325 MHz Pulsed Linac Beta<1 Test Area

1) Modulator construction (already underway).
2) Order the 325 MHz Klystron, for delivery in FY05.
3) In parallel, construct and begin cold tests of the RF fan out waveguide and directional coupler, to understand cross talk between couplers and related issues.
4) Continue development of the fast-ferrite tuner modules, with the goal of having functional prototypes at each required power level by the end of FY05.
5) Begin prototyping of 325 MHz cavities in various eta ranges by members of the SMTF collaboration.
6) Funds permitting, begin procurement of the H-/RFQ front end.
7) Continued development and simulation of LLRF control algorithms using the ferrite tuners.
8) Integrated system test of the front-end linac, 325 MHz Klystron, RF distribution, ferrite tuners and LLRF control.

RIA Production Tests in Beta<1 Linac Area

Additional lower-power CW RF systems to support production testing of RIA cavities and complete cryomodules may be added to this area if this proves attractive to the RIA project. [Incorporate words from ANL/RIA JLAB SMTF presentation]

M&S Funds and Labor

Upgrading of the facilities in the meson area will be required. The power systems and LLRF system for both frequencies we estimate will cost about $7M. The new 300 watt refrigeration system will cost about $5 M. A new injector will cost about $1.5M.The new cryomodules (with cavities) will cost about $3.0M each. The vacuum system, beam line magnets and power supplies, HVAC, and beam dump will cost about $1M. Initial cost estimate for the first two stages is about $20 M. The costs of these cavities and cryomodules are based on semi-production numbers. If cavity strings and cryomodules are assembled at Fermilab, infrastructure installation would require 5M$. We estimate $5M will be needed to fund activities by subcontracting to laboratories and US industry. This will be distributed according to sub-proposals made by the participating institutions. The total cost will be ~$45M over 4 years. We estimate labor costs to be about $40M for a total cost of about $85M over 4 years. We add 50% contingency to account for the additional costs associated with the initial costs for tooling and small quantity orders.

Summary

A group of laboratories and universities, with Fermilab taking the lead, is planning to construct a superconducting cryomodule test facility at Fermilab. The facility would be used for testing and validating designs for both pulsed and CW systems. The facility would bring together the expertise in cryogenic accelerators in the US and help form the accelerator team that would help design the main linac for the ILC. The SMTF will also fabricate several complete cryomodules in collaboration with US industry and laboratories. With this expression of interest, we are informing the laboratory of this activity and we are looking for direction on how you would like to receive such a proposal.

Appendix One

CW Facilities at the Superconducting Module Test Facility (SMTF)

Introduction

Superconducting RF structures operated in CW mode have advantages in providing extremely stable RF fields, inherently small perturbative effects on the beam, and with RF power requirements considerably less than equivalent normal conducting structures. Taking advantage of advances made in superconducting RF technology in recent years, several proposals have been developed in recent years for a variety of applications of CW SCRF, including energy recovery linacs (ERL's), recirculating linacs, and beam conditioning devices such as harmonic cavities for manipulation of longitudinal phase space, and transverse deflecting cavities.

The high quality factor of superconducting structures ($Q_0 \sim 10^{10}$) results in a very long filling time of 2.4 s for unloaded 1.3 GHz structures. Over coupling the cavity to the RF power input port reduces the quality factor and filling time, but requires additional RF power to overcome reflections introduced at the coupler. In some applications the beam loading may detune the cavity resonance such that input conditions closer approximate a match, but for many applications the system is not heavily beam loaded, and significant overcoupling has a direct consequence in increased rf power costs. In such cases then, the coupling and the filling time are limited primarily by the ability to provide feedback of the system against field fluctuations induced by microphonics. For example, a 50 Hz cavity/feed system bandwidth results in an external quality factor Q_{ext} of $2.6\text{x}10^7$ for the TESLA cavities and the cavity filling time is then several milliseconds. Typically, power is applied to pulsed standing wave cavities for about three time constants before the beam enters the structure, to allow time for energy to build up in the cavity so that the required field can be developed. The applications of interest discussed here require bunch rates significantly exceeding the capabilities of a system with 10-100 μs time constant, and the superconducting linac must be operated in continuous wave (CW) mode. The resultant power dissipation due to rf currents on the cavity inner surfaces increases significantly over the pulsed design parameters, for example a TESLA cavity operating at 20 MV/m cw dissipates approximately 40 W at liquid helium temperature, compared with ~ 1 W for the nominal pulsed operating mode. Operating in cw mode at a gradient of up to 20 MV/m requires development and testing of systems to accommodate the thermal load.

Application of CW SCRF in such facilities drives advances in a broad range of accelerator communities, including synchrotron light facilities, free-electron lasers (FELs), electron-ion colliders, and nuclear physics facilities. Recirculating linacs and ERLs, driven by CW SCRF linacs, are proposed advanced accelerator-based x-ray sources that allow high peak and average brilliance, high temporal and spatial coherence, and ultra short light pulses covering wavelengths from infra-red to x-rays, depending on the beam energy. Using stable beams from a CW SCRF linac allows utilization of the very low6-diemnsional electron beam emittance produced in high-brightness electron sources – a significant advantage over storage ring beam quality which is limited by stochastic effects (quantum emission, intra-beam scattering, radiation damping).

ERLs also allow high average photon flux by using very high beam power (high bunch rate) and recovering the beam energy. Energy recovery is achieved by passing the electron beam, following acceleration and x-ray production, back into the linac in the opposite phase to the accelerated beam. The energy in the electron beam is deposited into the SCRF cavities, building field for acceleration of fresh beam from the electron source, and providing enormous savings in electrical power. There have been several demonstrations of the ERL technique, most recently JLAB recovered 800 kW beam power in an ERL by recirculating 6 mA of beam current.

LBNL and MIT are developing FEL facilities based on proposed developments of the TESLA technology into the cw operating mode. These facilities are designed for high peak x-ray flux and brightness from FELs using high-quality electron beams accelerated in CW SCRF linacs, either recirculating or single-pass.

Cornell and TJNAF are developing light sources based on x-ray production by spontaneous emission in insertion devices with high coherence achievable from high-brightness electron beams, and using an ERL to achieve high average power. Cornell for example is conducting a study towards a 100 mA, 5 GeV beam with the equivalent of 500 MW of power.

At BNL a prototype ERL facility to demonstrate 0.5 A of cw current at about 20 MeV is under construction. For certain applications, in which a very high current (several hundred milliamperes to over an ampere CW) is required, there is an advantage to lower RF frequencies, and this facility will use a scrf photo injector electron source, and a 5-cell linac cavity at 703.75 MHz. BNL expects to demonstrate 20 MV/m cw operations at Q_0 values > $3x10^{10}$ and Q_{ext} > $1x10^7$ for low-beam-loading applications. The facility is expected to be operational by the end of 2006 as R&D towards electron cooling of RHIC. The BNL facility at 703.75 MHz could serve as a complementary SMTF for very high current CW tests. This facility is equipped with a 50 kW IOT amplifier, shielding, cryogenics support systems and will have a laser photocathode RF electron beam source for testing the module at very high current. The ERL configuration will allow for all the tests mentioned above to be carried out.

Goals for a CW SCRF test facility

Common R&D interests across many CW SCRF proposals are:

- Demonstrate 20 MV/m cw operations at Q values > $3x10^{10}$.
- Operate at 20 MV/m at a Q_{ext} > $1x10^7$ for low beam loading applications.

These goals encompass research and development topics critical for the development of CW operation for many upcoming applications. A CW SCRF test facility will also need to address the following major issues:

- Thermal management
- HOM damping
- Cavity tuning control

- Power coupler designs

The facility would provide for experimental determination of cavity Q values, gradient, stability, HOM characteristics, thermal load at a variety of locations within the cryomodule, input power, dark current.

The SMTF would allow test of CW SCRF cryomodules. The cryomodule and cavities can be constructed in US industry, and processed and tested using existing infrastructure at US labs. For example, cavities could be fabricated by AES, processed at TJNAF, and vertical tested at Cornell. The cryomodule components could be constructed at Meyer Tool and assembled at LANL or TJNAF. The string assembly can be at TJNAF or LANL.

In addition couplers and tuners and other cryomodule components would be fabricated to extend the full range of expertise and technology required for the major projects envisioned.

We would establish high gradient cw performance along with Q and dark current measurements without beam. Tuner tests, HOM measurements, and cavity microphonic tuning feedback systems test with the cryomodule would be performed to establish the necessary specifications.

Several rf structures are being developed for cw applications, at different frequencies and with different parameters, but with similar issues to be addressed.

Due to the high average beam power in some applications, HOMs and resultant deteriorating collective effects may be a particular concern. Beam tests of cw scrf structures will be important particularly for ERLs. Tests with beam could proceed after completion of static tests.

Thermal management

A nine cell TESLA cavity operating in cw mode at 20 MV/m will generate 42 W heat load as a result of rf current flow on the inner surfaces of the cavity. Added to this is 8.5 W heat entering the cavity niobium body from the input rf power coupler. This dynamic heat load is to be transferred through the niobium to the cavity outer surface in the super-fluid helium liquid bath, then to the super-fluid helium surface where boiling occurs at 1.8 K, without quenching the cavity. In a super-fluid helium test bath there is no problem transferring this heat from the cavity outer surface to the super-fluid helium surface, however, the transport of about 50 W from the cavity outer surface through the helium tank, the feed-pipe and the header-pipe configuration proposed for the TESLA cryomodules will require some modifications.

In order to provide sufficient heat transfer from the cavity outer surface to the surface of the liquid in the header, the following modifications to the basic TESLA cryogenic module design are under consideration:

- The number of feed pipes between the rf cavity helium tank and the two-phase helium stand pipe may be increased from one to two

- The helium feeds may enter the helium tank near the ends so heat can flow two ways along the rf cavity. If one puts the feeds at the one-quarter and three-quarter points along the cavity, the flow along the cavity is split four ways, and cavity cool down is not as effective

- The inside diameter of the helium tank may be increased to increase the spacing between the cavity convolutions and the cavity helium tank inner wall

- The liquid helium feed pipes from the stand-pipe to the tank may have their inside diameter increased

- The two-phase helium header pipe may have its inside diameter increased to allow heat to flow through the liquid in a half full pipe

The dynamic heat load in the cw scrf cavities is inversely proportional to the cavity unloaded Q value, Q_0. Development of high Q cavities, $Q_0 > 3\text{x}10^{10}$ has significant advantages to cw operations.

Lowering the temperature to 1.8 K increases the theoretical Q reachable to more than $6\ \text{x}10^{10}$. Allowing for a reduction by a factor of two due to residual losses, a target of $3\text{x}10^{10}$ would reduce the dynamic heat load to 13 W/m. Excellent magnetic shielding will be necessary to screen the earth's field down to about one mGauss. (The earth's field flux quanta get trapped in the niobium walls, due to the presence of imperfections, impurities and oxides, thereby limiting the Q-value).

Operating at 1.8 K to reduce the BCS resistance and increase the theoretical maximum Q-value will demand larger pumps to reach the lower helium vapor pressure corresponding to 1.8 K.

Control of cavity HOM's and wakefields

For high average power operations, cavity Higher Order Modes (HOMs) may present significant problems due to the perturbative effects of the wake fields persisting from one electron bunch to the next.

Since the SCRF cavities require very smooth boundaries and transitions, HOM damping devices are located at the ends of the cavities, in the beam pipe, and may be in a cold section of the cryomodule or external in a warm section.

Effective HOM damping is required to reduce beam impedance, raise coupled-bunch instability thresholds (Beam Break-Up or BBU), and allow stable operations.

Beam tests will be particularly important for applications with high average power.

Feedback control of cavity tuning variations

A significant problem for the use of superconducting cavities is the fact that systematic as well as random tuning errors are orders of magnitude larger than this intrinsic bandwidth. An example for the systematic part is by the detuning by the radiation pressure forces or Lorentz force detuning, which may be as large as 360 Hz for a gradient of 20 MV/m. While this is of great concern for pulsed cavities, it can be easily corrected in the cw application where the field is continuous.

More serious are the random tuning deviations. The random tuning perturbations fall in two categories:

A. Relatively slow perturbations, with periodic intervals in the minute range. Random variations of the helium pressure represent a common cause.

B. Fast perturbations due to micro phonics in the acoustic frequency range, caused by local mechanical stimuli (pumps, turbulence in the helium flow etc). The response is shaped by structural resonances and directional sensitivities of the cavities.

Slow mechanical tuners may be used to eliminate the slow perturbations. Faster feedback systems are required to control the effects of micro phonics, which may extend their influence to approximately ± 25 Hz from the RF frequency. To control against such rapid tuning variations, the RF system must provide sufficient generator power to establish the nominal field in the cavity under worst-case conditions of full detuning by micro phonics. The RF power requirement P_g can be expressed analytically by:

$$P_g = \frac{P_c}{4\,\beta}\left\{(1+\beta+b)^2 + \left[2\,Q\,\frac{\Delta f}{f} - b\,tan(\Psi_B)\right]^2\right\}$$

where P_c is the cavity wall dissipation, b is the ratio beam power/cavity wall power, ψ_B is the beam stable phase from crest, ß is the cavity coupling factor, and Δf is the cavity detuning (determined by the micro phonics spectrum).

Thus, the requirement to maintain field in the cavities under the influence of micro phonics has strong impact on the system RF power requirements, and thus costs. Techniques to minimize detuning from micro phonics may have significant impact in CW SCRF systems design.

Power couplers

Superconducting rf systems require very little power to generate large accelerating gradients – as mentioned previously the TESLA cavities may develop 20 MV/m with only 40 W input power under ideal conditions. In order to accommodate for tuning variations as discussed above, however, significantly larger rf drive power is required, typically 10-15 kW per cavity.

Power couplers must transport this power from warm waveguide or coaxial supply lines, through intermediate temperatures, thermally isolating sections, vacuum windows, to liquid helium temperature components, and have mechanically adjustable components, while avoiding multipacting and excessive heating.

Infrastructure Requirements for a CW SCRF Test Facility

The facility would provide rf power, cryogenic fluids and transport, and test beams of electrons.

The cw tests will require a klystron (or IOT) with approximately 15 KW of power to establish 20 MV/m operating field with control margin for dealing with microphonics at the optimum external Q value, estimated to be about $2x10^7$. A high voltage power supply and a small amplifier are needed to supply the klystron.

The cryogenics plant for cavities operating cw at 20 MV/m with Q_0 $1x10^{10}$ would be 60 w/m at 1.8 K, allowing for a safety factor of 1.5. Assuming advances in technology allow half the theoretical Q-value, then the cw cryomodule refrigerator would be sized for about 22 watt/m at 1.8 K and about 5 watt/m at 4.5 K.

We outline below possible studies with a 100-300 MeV electron beam for the SMTF. First, the RF performance of the cavities can be measured directly with beam and secondly, the impact of the cavity on the beam can be assessed. An initial set of measurements would include:

- Beam energy: a spectrometer would provide an independent and accurate measurement of the accelerating gradient experienced by each bunch along a train, under the influence of cavity wake fields. RF techniques are not as accurate.

- Long Range wake-field characterization: HOM impact on multi-bunch dynamics (emittance and energy spread). Especially important for high repetition linacs such as high power free electron lasers and electron cooling at RHIC. High beam currents may allow the observation of the beam break-up instability.

- Tests of low-level RF: compensating beam loading effects on the beam energy spread

- Impact of the SCRF cavity on transverse beam dynamics: measure the cavity transfer matrix and impact of field asymmetries near the input power and HOM couplers on beam dynamics.

Appendix Two

Electron beam: Fermilab/NICADD photo injector laboratory

Introduction

Since 1992, Fermilab has been engaged in the production of high-brightness electron beam. In conjunction with the TESLA collaboration, it has constructed and operated an L-band (1.3 GHz) photo injector, a copy of which was installed at the TESLA test facility in DESY Hamburg, for various tests, especially for the proof-of-principle UV SASE free-electron laser experiment. The Fermilab/NICADD photo injector laboratory (FNPL) is used as a test facility for beam dynamics studies associated to high brightness beam and its associated diagnosis, along with application to advanced accelerator physics.

Facility and existing capabilities

FNPL consists of a 1+1/2 cell L-band rf-gun equipped with a high quantum efficiency Cesium-Telluride photo-cathode allowing the photo-emission of electron bunches with charge up to ~20 nC). The thereby generated bunches are further accelerated, up to 16 MeV, by a downstream superconducting TESLA cavity operating with a nominal accelerating gradient of ~12 MV/m (see Fig.1). Downstream of the cavity the beam line includes a set of quadrupoles and steering dipoles elements for beam focusing and orbit correction, a skew quadrupole channel that allows the generation of flat beam using an incoming angular-momentum dominated beam, and a magnetic bunch compressor chicane which can enhance the bunch peak current up to approximately 2.5 kA. The diagnostics for measuring transverse beam properties consist of electromagnetic beam position monitors, optical transition radiation (or

YaG) screens (for measuring beam transverse density) and three emittance measurements station based on the multi-slit mask technique. The bunch length measurement is performed by a streak camera that streaks optical transition radiation pulses emitted by the bunch. An alternative frequency-domain bunch length diagnostics based on Martin-Puplett interferometry of coherent transition radiation is also available. Downstream of the beamline, the beam can be bent in a dispersive section, to measure the beam energy distribution, or transported in a straight ahead user experimental area. The FNPL facility can be operated remotely. So far teams from LBNL, and DESY have used this capability to remotely perform beam physics experiments.

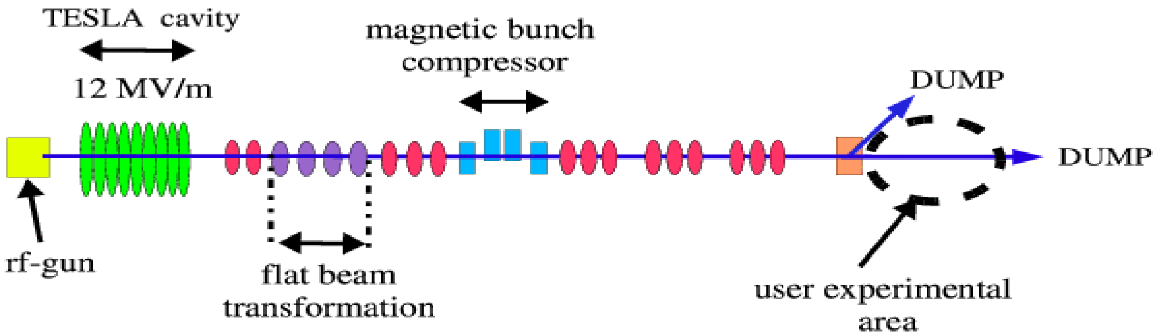

Figure 1: Overview of the FNPL facility in its present configuration.

Current activities

Several beam dynamics and beam diagnostics activities are being actively pursue at the FNPL photoinjector. Our main current efforts are (1) photoinjector production of flat beam with emittance high emittance ratio (goal > 100), (2) longitudinal beam dynamics studies using a two macro-particle bunch, (3) study of emittance control versus shape of the photo-cathode drive-laser, and (4) emittance evolution of highly charge electron bunches (15 nC). All these experimental studies also involve theoretical and numerical modelling.

Collaborators from NIU and UCLA have been performing experiment on plasma-wakefield acceleration. The experiment consists of injecting a high charge (typically 10 nC) short (typically 3 ps) electron bunch in an Argon plasma. The experiment has both concentrated on demonstrating beam plasma deceleration and acceleration. Recently the amplitude of the plasma wake-field has been measured to be 130 MV/m. A refinement of this experiment based on a drive/witness bunch set-up has been commissioned by splitting the cathode drive-laser pulse into two pulses whose transverse size and charge can be independently controlled.

Recently our UCLA collaborators have installed an experiment devoted to realize an electron source based on the so-called plasma-density transition. The experiment is now in its commissioning phase.

A team from the University of Rochester has developed a laser functioning on the TM_{01}* mode, a mode with a longitudinal electric field component. The laser is now ready and we plan, after the foreseen energy upgrade of FNPL (see next section), to “couple” the laser and electron beams with an open iris structure. At energies above 40 MeV, we will be able to observed laser-based acceleration..

Upgrade Plans

The TESLA collaboration has recently offered to provide a second TESLA cavity that has been tested to achieve accelerating gradient up to approximately 35 MV/m. We plan to install this second cavity downstream of the first one to boost the beam energy to approximately 45 MeV. Such an energy increase (by a factor ~3 compared to the present setup) will considerably reduce the impact of space-charge forces on the beam dynamics and thereby resulting in a better control of transverse envelope and emittance. The FNPL upgrade will also allow the support of various "user experiment" like, for instance, the laser acceleration experiment (using the laser developed by University of Rochester).

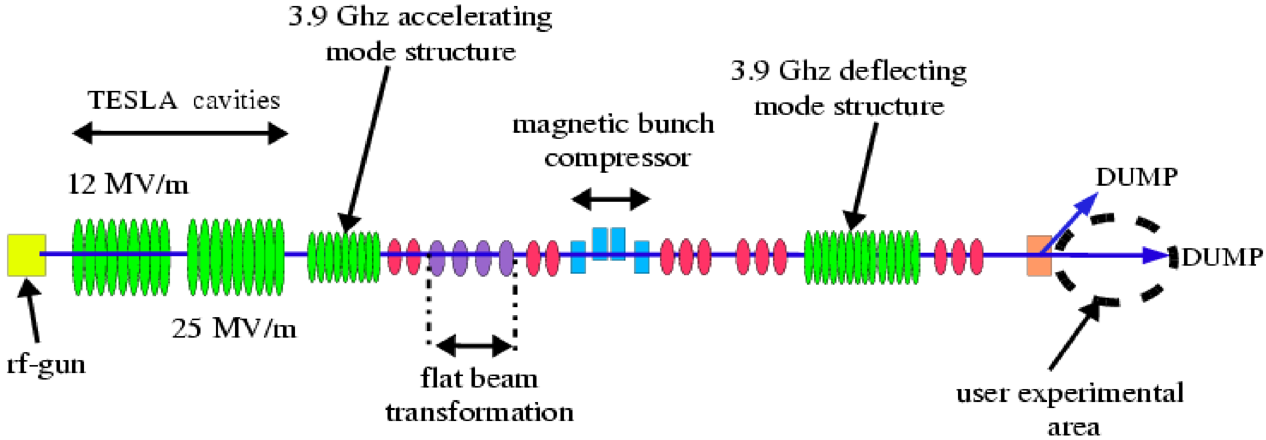

Figure 2: Overview of the upgraded FNPL facility. The facility will incorporate two TESLA cavities, one accelerating and one dipole mode 3.9 Ghz cavities.

In the process of this beamline extension we also configure the beam line to allocate room for two 3.9 GHz superconducting cavities being developed at FNAL: a deflecting and an accelerating mode cavity. The deflecting mode cavity was developed in the context of the Kaon separation out of the secondary beam produced at the main injector at FNAL (so-called CKM experiment). It has also applications in the LUX proposal at LBNL to generate ultra-short X-ray pulses. The deflecting mode cavity was developed to linearize the longitudinal phase space and thereby enhance the peak current of accelerator working on the 1.3 Ghz frequency. Such a "linearizer" has applications in the context of light source (TESLA VUV/X-ray FELs, LUX project at LBNL, etc…) and also linear collider (TESLA post damping ring bunch compressor). At FNPL the use of these two cavities simultaneously will provide a direct measurement and optimization tool of the longitudinal phase space linearization concept. The deflecting cavity alone also provides a unique diagnostics that should allow the measurement of beam parameters within the bunch (so-called slice parameters) and provide a refinement in understanding the beam dynamics of space-charge-dominated electron beams. A schematic of the proposed FNPL upgrade is shown in Figure 2.

FNPL upgrade as an e- injector for SMTF

In the context of SMTF, the upgraded version of FNPL would provide an ideal injector that could, at a later stage, be transplanted on the SMTF site. A configuration consisting of an rf gun followed by the two TESLA cavities, as planned to be operated at FNPL, would provide a transverse emittance-compensated beam. According to preliminary numerical studies, such a beam could then be subsequently accelerated by a TESLA accelerating module operated at any accelerating gradient without significantly impacting the transverse emittance (see example in Figure 3). Such a feature means that an injector consisting of an rf-gun with two TESLA cavities only (in the present case operated at 12.5 and 25 MV/m average accelerating gradient) would be an independent entity that could provide controllable beam parameters to be injected in SMTF. The current FNPL facility (one rf-gun followed by one TESLA cavity) does not provide such a capability: the beam is still strongly emittance-dominated: even over a short drift the beam parameters tend to degrade. Therefore FNPL upgrade, while enabling the extension of the current advanced accelerator physics program, could also be viewed as the first phase of SMTF. Parametric studies and subsequent optimization of the system should allow the production of high quality beam with the nominal linear collider charge such a beam could then be injected. The FNPL upgrade will also provide operational experience and training for future scientist working at SMTF. We anticipate the upgrade of FNPL (to be ready for SMTF) to include: the installation of the TESLA cavity offered by DESY, an upgrade of the photocathode drive-laser (to improve the reliability of the facility) and at a later stage the installation of the two 3.9 GHz cavities. In parallel we advise the development and construction of a new symmetric rf-gun cavity such as the one in operation at the TTF-2 FEL facility.

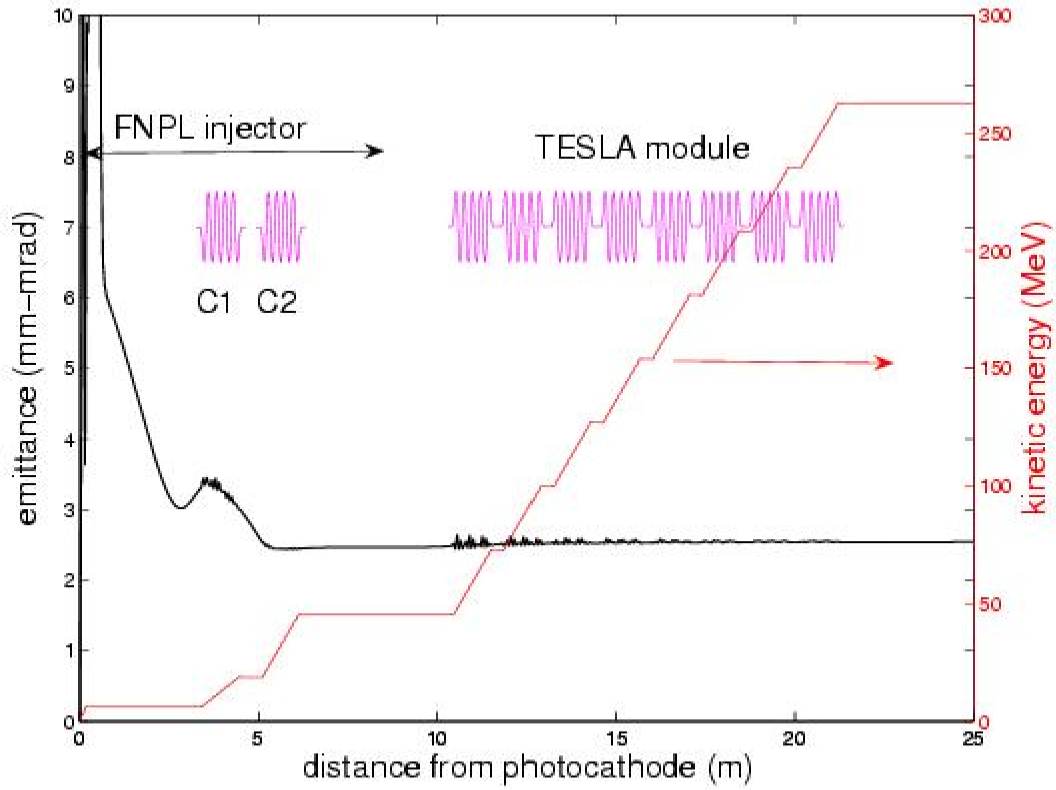

Figure 3: Example of transverse emittance (black) and kinetic energy (red) evolution for a 3.2 nC bunch (TESLA nominal charge). C1 and C2 are the two TESLA cavities to be operated in the FNPL upgrade (here operated at 12.5 and 25 MV/m average accelerating gradient). The upgraded FNPL injector extend from z=0 to z=8 m. The beam is then injected in a TESLA accelerating module. The magenta curves stands for the longitudinal fields, i.e. the location of the TESLA cavities.

Appendix Three

For more information on cryogenics, cryomodule structures and supporting infrastructure as well as test stands for single cavities please see URLs

http://rutherford.hep.upenn.edu/~lockyer/SMTF/cryogenics.doc

http://rutherford.hep.upenn.edu/~lockyer/SMTF/Cryomodule-Infrastructure.doc

http://rutherford.hep.upenn.edu/~lockyer/SMTF/teststands.doc